Any strip of elastic material will do for the above if the length be suitable—one readily finds the proper length by trying larger and smaller circles.

VI. "On the Physiology of Asphyxia, and on the Anæsthetic Action of Pure Nitrogen." By GEORGE JOHNSON, M.D., F.R.S. Received January 26, 1891.

(Abstract.)

The main object of this paper is to bring forward additional evidence in support of the theory that the immediate cause of death in cases of asphyxia is the arrest of the pulmonary circulation. I have to express my obligation to my friend Mr. Charles James Martin, M.B., B.Sc., Demonstrator of Physiology in King's College, for the time and labour which, by my request, he has bestowed in the performance of numerous and various experiments, the results of which will, I think, throw much light upon the complex phenomena of asphyxia. It is right to mention that Mr. Martin is not responsible for my interpretation of the results of his experiments.

All the experiments were performed on animals under the influence of anæsthetics, and every animal was finally killed by deprivation of air.

Animals—rabbits, cats, and, in a few cases, dogs—were asphyxiated either by ligature of the trachea, by the paralysing influence of curara, or by causing them to inhale a gas containing no free oxygen, viz., nitrous oxide, pure nitrogen, hydrogen, and carbonic acid gas. In all these experiments, re-inspiration of the gases was avoided by allowing the expired gas to escape through a T-tube fixed in the trachea.

During the performance of the experiments, in most cases, the chest and pericardium of the animals were opened so that the relative fulness of the cavities might be readily observed. In all the experiments, the results, as regards distension of the heart's cavities, were essentially the same, no matter whether the air was simply excluded or whether an azotic gas (*i.e.*, a gas, not in itself poisonous, but unable to support life) was substituted for atmospheric air; the only difference being that when an azotic gas is inhaled the phenomena are far more rapidly produced, in consequence of the more speedy displacement of oxygen from the lungs.

The principal changes in the heart's cavities were, first, distension of the left cavities; second, enormous distension of the right cavities with diminished distension of the left, the circulation being apparently arrested by the inability of the right cavities to empty themselves, in

consequence of obstruction in front. That the arrest of the circulation is not due to paralysis of the heart's walls, by the circulation of venous blood through its tissues, seems to be proved by the following experiment.

Into the trachea of a small dog, with the chest and pericardium opened and kept alive by artificial respiration, a glass T-tube was introduced, through which pure nitrous oxide was passed into the lungs, whilst the expired gases escaped into the air. As usual, first the left then the right cavities became distended, and in one minute the heart's action had nearly ceased, with over-distension of the right side. Then inhalation of nitrous oxide, *impregnated with the vapour of nitrite of amyl*, was substituted for pure N_2O, by means of a two-way stopcock, and the result was that almost immediately the distension of the right cavities began to subside, and in two minutes they had nearly regained their normal size.

The explanation is, that the circulation, having been arrested by the contraction of the arterioles, was, for a time, restored by the paralysing influence of nitrite of amyl upon those vessels, while atmospheric air was strictly excluded.

Additional evidence of the influence of the arterioles in arresting the circulation during the progress of asphyxia is derived from the fact that a sufficient dose of such agents as are known to paralyse the arterioles, *e.g.*, curara and atropine, prevents over-distension of the heart's cavities, and considerably prolongs the life of the animal.

This is conclusively shown by experiments performed by Mr. Martin, the details of which are given in the paper of which this is an abstract.

It has been suggested that the distension first of the left then of the right side of the heart in asphyxia is the result solely of *systemic* arterial contraction, the impediment acting backwards from the left side of the heart, through the lungs, to the right cavities and the systemic veins. The main objection to this theory is the fact that, when the chest is opened immediately after death from asphyxia, the lungs are found extremely pale, from anæmia of their minute vessels, and in a corresponding degree collapsed. Backward pressure from the left side of the heart, sufficient to greatly distend the right cavities, must of necessity involve engorgement of the pulmonary capillaries.

That there is a certain amount of backward pressure from the primary distension of the left heart, extending as far as the pulmonary *veins*, would seem to be proved by observations made by Mr. Martin to the effect that a manometer in a branch of a pulmonary vein indicates an early and continuous increase of pressure during the progress of asphyxia; but that this backward pressure does not extend to the right side of the heart is shown by the fact that in the

last stage of asphyxia, while the right cavities are in a state of extreme distension, the left are, as a rule, flaccid and comparatively empty, the lungs themselves, as before mentioned, being extremely anæmic and collapsed. The condition of the heart's cavities in the successive stages of asphyxia was clearly shown by an experiment which Dr. Rutherford performed in my presence in 1873. The details of this experiment are given in my paper (see diagram with tracing).

The true explanation of these facts appears to be that, during the latter stages of asphyxia, the pulmonary arterioles contract, and cause the extreme distension of the right cavities with anæmia of the pulmonary capillaries, and a corresponding defective supply to the left cavities of the heart.

The continued increase of pressure in the pulmonary vein, observed by Mr. Martin, may perhaps be accounted for by the fact that in the last stage of asphyxia the suction power of the left auricle is impaired, partly by anæmia of the cardiac tissue, consequent on the contraction of the arterioles—both pulmonary and systemic, the coronary included—and partly by the fact that the small amount of blood with which it is supplied is more or less completely deoxidised.

[I venture further to suggest the following explanation of the increased blood pressure which has been observed to occur in the pulmonary veins during the successive stages of asphyxia. During the first stage, when the left cavities of the heart are over-distended, as seen in Dr. Rutherford's experiment, there would be a backward pressure extending through the pulmonary veins and capillaries, even, perhaps, to the branches of the pulmonary artery; but this backward pressure from the left side of the heart must obviously cease when, in the last stage of asphyxia, those cavities are nearly empty of blood. When, however, portions of the ribs are removed in order to introduce a manometer into one of the pulmonary veins, a new and artificial cause of obstruction to the pulmonary venous circulation is introduced.

The collapse of the lung, which results from the breach in the chest wall, compresses the thin-walled pulmonary veins more than the corresponding arteries, and so increases the intra-venous pulmonary pressure. It is an acknowledged fact that the comparatively slight compression of the pulmonary veins which occurs towards the end of a normal expiration lessens the flow of blood into the left side of the heart.* It is obvious, however, that the pulmonary venous obstruction thus caused must be very much less than that occasioned by the extreme collapse of the lung which results from an opening in the wall of the chest.—March 3, 1891.]

* See Dr. M. Foster's 'Physiology,' 5th edition, p. 618.

Drs. Bradford and Dean have proved not only the existence of pulmonary vaso-motor nerves, but also that they leave the cord higher up than the systemic vaso-motor nerves (*vide* 'Roy. Soc. Proc.,' vol. 45).

These authors remark that "it is probable that the pulmonary vaso-motor mechanism is but poorly developed, compared with that regulating the systemic arteries."

It would indeed be an incredible physiological anomaly if the vessels of an organ, through which the entire blood of the body has constantly to pass, had not the same regulating and resisting power, compared with the force of the right ventricle, as that possessed by the systemic arterioles.

Mr. Martin has found by introducing a manometer into a branch of the pulmonary artery of a moderate sized cat, while the remaining branches were suddenly obliterated, that the blood pressure was rather more than doubled, rising from 17 mm. to 36 mm. of mercury.

Mr. Martin also found that, during the last stages of asphyxia, the pressure in the pulmonary artery is nearly doubled, while that in the carotid is rapidly falling.

No experiment that has hitherto been devised can accurately measure the resisting power of the pulmonary arterioles or the actual force of the right ventricle, for the reason that the arrest or great diminution of the pulmonary circulation weakens the muscular walls of the heart by cutting off the blood supply through the coronary arteries.*

The increase of systemic arterial blood pressure, which instantaneously follows re-admission of air into the lungs, after the circulation had been almost completely arrested by exclusion of air, seems to prove that the heart's walls are not *paralysed* by venous blood. On the other hand, such a speedy restoration of the circulation is at once explained by the sudden removal of the obstruction which had been caused by the contracted pulmonary arterioles.

* [Since this paper was communicated to the Royal Society, Dr. M. Foster has done me the favour to refer me to a paper by Professor Knoll ("Der Blutdruck in der Arteria pulmonalis," 'Sitzber. Akad. Wiss. zu Wien,' vol. 97, Abth. 3, p. 207). Dr. Knoll endeavours to measure the normal blood pressure in the pulmonary artery of the rabbit by dividing the sternum, opening the pericardium, and introducing a tube into the pulmonary artery without wounding the pleura. Thus, the blood pressure is observed while normal respiration is carried on.

Dr. Knoll, however, admits that the atmospheric pressure, consequent on the opening of the mediastinum, cannot be without some influence upon the circulation, so that even this careful and difficult mode of procedure is not free from sources of error.—March 3, 1891.]

Conclusions relating to Asphyxia.

That the immediate cause of death is the arrest of the pulmonary circulation appears to be proved by the following facts:—

1. When the chest of an animal is opened immediately after death caused by a ligature on the trachea, the right cavities of the heart are found enormously distended, while the left are comparatively empty.

2. When the heart of an animal is exposed during the progress of asphyxia, the right cavities are seen to become distended, while the left, which had been previously gorged, are found to be collapsed and nearly empty.

3. In the last stage of asphyxia there is a continuous increase of pressure in the pulmonary artery while the systemic arterial pressure is falling.

4. That the arrest of the circulation through the lungs is due to the contraction of the pulmonary arterioles appears to be proved by the influence of agents which paralyse the arterioles, namely, nitrite of amyl, atropine, and an excessive dose of curara; the effect of which is that deprivation of air is unattended by distension of the right cavities of the heart and other evidence of obstructed pulmonary circulation, the life of the animal is prolonged for several minutes, and death ultimately results from the influence of venous blood upon the cardiac and nervous tissues.

The anæsthetic action of nitrogen alone or with a small proportion of oxygen. The phenomena which result from the inhalation of nitrous oxide as an anæsthetic are strictly analogous with those observed in the early stages of asphyxia.*

Some writers maintain that the anæsthetic action of nitrous oxide is due to its preventing access of free oxygen to the system, others believe that it has a specific anæsthetic action. It occurred to me that light might be thrown upon this subject by the administration of pure nitrogen. Accordingly I obtained from the Scotch and Irish Oxygen Company, of Glasgow, a cylinder containing 100 cubic feet of compressed nitrogen in which the proportion of oxygen was only 0·5 per cent. by vol., whilst that of the CO_2 present was 0·3 per cent. As a preliminary trial, Mr. F. W. Braine was good enough to administer this gas in five instances to members of the staff of King's College, who volunteered to inhale it.

The result was, in each case, the production of complete anæsthesia and of general phenomena precisely similar to those observed from the inhalation of nitrous oxide. Encouraged by these results, Mr.

* *Vide* the author's 'Essay on Asphyxia,' p. 30.

Braine felt justified in administering the gas to patients at the Dental Hospital. Nine patients took the gas. In every case, the result was the production of complete anæsthesia, with general phenomena precisely similar to those observed during nitrous oxide inhalation. The pulse was first full and throbbing, then feeble; in the advanced stage respiration was deep and rapid, with lividity of the surface, dilated pupils, and more or less jactitation of the limbs; the only difference, in the opinion of some of those present, being that the anæsthesia was less rapidly produced, and somewhat less durable than that from nitrous oxide, though in each case the tooth was extracted without pain.

On a subsequent occasion, the same gas was administered by Dr. Frederic Hewitt at the Dental Hospital. Nine patients took the gas. The maximum period required to produce anæsthesia was 70 seconds, the minimum 50 seconds, and the mean time 58·3 seconds.

In one case, two teeth were extracted without pain; in one only was pain experienced, and in that case, the tooth having been broken and not extracted, the patient said she felt a "smashing up."

I subsequently obtained from the same Company a cylinder containing compressed nitrogen with 3 *per cent. of oxygen*, and a second cylinder containing nitrogen with 5 per cent. of oxygen. These gases were also administered by Dr. Hewitt to patients at the Dental Hospital, with the following results.

Five patients took the 3 *per cent.* gas. Anæsthesia was complete in 75 seconds (max.), and in 60 seconds (min.), the average time required being 67·5 seconds. In each case, the tooth was extracted without pain, the duration of anæsthesia being somewhat longer than with pure nitrogen. In each case there was lividity, dilatation of pupils, and more or less jactitation.

Four patients took the nitrogen containing 5 *per cent. of oxygen.* With this mixture, the time required for the production of anæsthesia ranged from 75 to 95 seconds, the average time being 87·5 seconds.

In each case there was complete anæsthesia, during which one patient had three molars extracted. Although she said she felt the last two, the sensation appeared to be that of a pull, and not of acute pain.

In most of these four cases there was slight lividity before the removal of the face-piece. In only one case was there slight jactitation of the limbs; the other three patients were perfectly quiescent.

For the information of those who may be disposed to investigate the anæsthetic action of nitrogen with a small proportion of oxygen, I may mention that Brin's Oxygen Company (69, Horseferry Road, Westminster) are prepared to supply nitrogen containing from 4 to 7 per cent. of oxygen at the same rate as they charge for pure oxygen.

Below 4 per cent. of oxygen nitrogen could be supplied only by special arrangement and probably at increased cost.

Presents, February 5, 1891.

Transactions.

Berlin :—Gesellschaft für Erdkunde. Verhandlungen. Bd. XVII. No. 10. 8vo. *Berlin* 1890. The Society.

Cambridge, Mass. :—Harvard College. Museum of Comparative Zoology. Bulletin. Vol. XX. No. 5. 8vo. *Cambridge* 1890. The College

Harvard University. Catalogue. 1890–91. 8vo. *Cambridge* 1890. The University.

Christiania :—Videnskabs-Selskab. Forhandlinger. 1889. 8vo. *Christiania.* The Society.

Europe :—Congresso Internacional de Anthropologia e Archeologia Prehistoricas. Relatorio ácerca da Decima Sessão. 4to. *Lisboa* 1890. The Congress.

Florence :—Biblioteca Nazionale Centrale di Firenze. Bollettino delle Pubblicazioni Italiane. Num. 97–121. 8vo. *Firenze* 1889–90; Indici e Cataloghi. Codici Palatini. Vol. II. Fasc. 1–2. 8vo. *Roma* 1890; Manoscritti di Filippo Pacini. 8vo. *Roma* 1889. The Library.

Helsingfors :—Finska Vetenskaps-Societet. Bidrag till Kännedom af Finlands Natur och Folk. Häft 48. 8vo. *Helsingfors* 1889; Öfversigt. 1888–89. 8vo. *Helsingfors* 1889. The Society.

Innsbruck :—Ferdinandeum für Tirol und Vorarlberg. Zeitschrift. Folge III. Heft 34. 8vo. *Innsbruck* 1890. The Ferdinandeum.

Leipsic :—Astronomische Gesellschaft. Catalog. 1. Abtheil. Zone +65° bis +70°. Beobachtet auf der Sternwarte Christiania. 4to. *Leipzig* 1890. The Society.

Königl. Sächs. Gesellschaft der Wissenschaften. Abhandlungen (Philol.-Histor. Classe). 8vo. *Leipzig* 1890. The Society.

London :—Royal Meteorological Society. Catalogue of the Library. 8vo. *London* 1891. The Society.

Magdeburg :—Naturwissenschaftlicher Verein. Jahresbericht und Abhandlungen. 1889. 8vo. *Magdeburg* 1890. The Society.

Manchester :—Owens College. Studies from the Physiological Laboratory. Vol. I. 8vo. *Manchester* 1891. The College.